Overview of Current Cryogenic Propellant Operations for Space Shuttle

General Overview

NASA primarily uses liquid hydrogen (LH_2) and liquid oxygen (LO_2) as a fuel propellant and oxidizer propellant, respectively. In the space shuttle, LH_2 and LO_2 are combusted in the Space Shuttle Main Engines for the 8½ minute flight from KSC to orbit. Other minimal uses for LH_2 and LO_2 provide reactants to the fuel cell and breathing environment (LO_2 only).

Acquisition

LH_2 and LO_2 are transported as a liquid to Kennedy Space Center (KSC) by tanker truck and are transferred to launch pad storage tanks through a manifold of five connections. Figure 1 shows a typical LO_2 transfer from the tanker to launch pad storage tank. The commodity transfer is accomplished by pressurizing the tankers and flowing the commodity through a 3" line to the top of the storage tanks and approximately 5-15% of LH_2 and LO_2 are vaporized during the transfer.

The procurement specification for LH_2 is MIL-PRF-27201, while the procurement specification for LO_2 is MIL-PRF-25508 – Grade A (with a minimum purity of 99.85%).

Figure 1: Liquid Oxygen Transfer to Launch Pad Storage Tank.

Storage Tanks

A LH_2 storage tank and a LO_2 storage tank exists at both space shuttle pads, LC-39A and LC39B. On each pad, the storage tanks are separated by a distance of several hundred meters and hold just under a million gallons of LH_2 and LO_2. During normal storage conditions, the storage tanks are kept at a pressure slightly above atmospheric pressure (0-5 psig). Each LO_2 storage tank is a double-walled vessel with a gaseous nitrogen purge in the annular space and loses approximately 1,000 gallons/day of LO_2. Each LH_2 storage tank is double-walled vessel with a vacuum in the annular space and loses 400 gallons/day of LH_2, nominally.

Launch Pad Transfer System

Liquid oxygen is transferred from the LO_2 storage tank to the space shuttle external tank (ET) through a vacuum-jacketed transfer line using a pump. Liquid hydrogen is transferred from the LH_2 storage tank to the ET through a vacuum-jacketed transfer line. The LH_2 storage tank is pressurized to accomplish the LH_2 transfer.

Space Shuttle Propellant Loading

Cryogenic propellant loading in space shuttle operations typically begins 10 hours before launch. The cryogenic propellant, LH_2 and LO_2, are loaded into the ET and the loading operation occurs in three phases. The first phase is a slow fill, which chills down the transfer system and provides liquid to 2% inside the external tank. The second phase is a fast fill that fills the ET from 2% to 98%. The third phase is a slow fill that completes the fill of the ET. The filling process takes approximately three hours to complete. After the ET is loaded with LH_2 and LO_2, the process enters a phase called stable replenishment for the remainder of the launch countdown (typically 7 hours). Stable replenishment replaces the LH_2 and LO_2 evaporated from the ET, thermally conditions the rocket engines, and maintains propellant quality (temperature and pressure). A successful launch consumes approximately 485,000 gallons of LH_2 and 225,000 gallons of LO_2.

In the event of a scrubbed launch attempt, the LH_2 and LO_2 is drained from the ET back to the storage tank via pressure and gravity and takes 1-2 hours to complete. Preferably, the ET will be inerted through a process of introducing a helium purge into the ET continues well after the cryogenic propellant from the ET is recovered. A scrubbed launch attempt consumes about 100,000 gallons of both, LH_2 and LO_2.

In summary, a launch consumes more cryogenic propellant than a scrub. However, the number of scrubs capable of being supported is dependent upon the amount of liquid in the storage tank.

Other Launch Pads and Vehicles

The US Air Force currently uses 2 different styles of launch vehicles at Cape Canaveral Air Force Station (CCAFS). The Air Force calls them Evolved Expendable Launch vehicles (EELV) which are the Delta IV and the Atlas V. They have similar operations as the Space Shuttle from a qualitative perspective, however, the quantities of propellant consumed and the duration propellant loading vary depending on what type of vehicle and its configuration (for example, Delta IV has a Medium and Heavy configuration). Both vehicles use LO2 for the vehicles' oxidizer. To fuel the vehicles' main engine, the Atlas V uses RP-1 and the Delta IV uses LH_2. Both use similar storage tanks, transfer systems, and propellant loading procedures as the Space Shuttle.

A successful Delta IV launch consumes approximately 175K gal LH_2 for the Medium configuration and 450K gal LH_2 for the Heavy. For liquid oxygen, the Medium configuration uses about 80K gal LO_2 and the Heavy about 200K gal LO_2.

A successful Atlas V launch consumes ~75K gal of LO_2 and uses RP-1 as fuel. A Delta IV LO_2 storage tank loses approximately 500 gal a day, and the LH_2 storage tank loses about 700 gal a day. An Atlas V LO_2 storage tank loses approximately 330 gal a day.

A scrubbed Delta IV launch attempt consumes ~50K gal of LH_2 for the Medium configuration and ~160K gal of LH_2 for the Heavy. For liquid oxygen, the Medium configuration consumes ~34K gal of LO_2, and the Heavy ~75K gallons. A scrubbed Atlas V launch attempt consumes ~ 15,000 gal of LO_2.

Overview of Current Purge Gas Operations for Space Shuttle

General Overview

NASA uses gaseous nitrogen (GN_2) and gaseous helium (GHe) for purge and pressurization requirements at various facilities at KSC and CCAFS. The base requirements include normal vehicle processing and is differentiated from launch requirements, which are peak requirements the day of launch.

Acquisition

GN_2 is transported from a near-site contractor-owned, contractor-operated plant through 40 miles of distribution pipeline throughout KSC and CCAFS. The procurement contract requires a delivery pressure between 5,200 psi to 7,000 psi and maximum flow rate of 24,000 scfm. For space shuttle support, the GN_2 goes through the Converter Compressor Facility prior to LC-39 distribution. From the CCF, GN_2 is regulated down to 5,858 psi for the high pressure GN_2 and down to 150 psi for low pressure GN_2. The low pressure GN_2 pipeline runs only to LC-39A and LC-39B and is used only for launch consumption. The procurement specification for nitrogen is MIL-PRF-27401-Grade B.

Helium is transported to KSC by liquid tanker and is delivered to the CCF. The CCF currently has 2-30,000 gallon liquid helium dewars that are planned be activated before October 2009. The CCF converts liquid helium to GHe and subsequently compresses the GHe to ~5,800 psi. The procurement specification for helium is MIL-PRF-27407-Grade A.

Pneumatic Storage

From the CCF, GN_2 and GHe is distributed to each pad, LC-39A and LC-39B, as well as Vehicle Assembly Building (VAB) with each location having a battery of GN_2 and GHe storage vessels. Both systems have a maximum pressure of 5,868 psi. There are no storage pressure vessels for the low pressure GN_2.

Base Consumption

The base consumption for GN_2 is approximately 1500 standard cubic feet per minute (scfm) for LC-39 area (space shuttle only). The GN2 contractor is required to maintain the pipeline pressure above 5,200 psi.

The base consumption for GHe is averaged at 75 scfm for the LC-39 area. Current operations allow the LC-39 pipeline system pressure to decay and CCF personnel operate compressors to restore GHe pressure during second shift. Any peak processing GN_2 or GHe requirements are buffered by the storage vessels in the LC-39 area.

Launch Consumption

The GN_2 contractor brings pipeline pressure above 6,500 psi prior to a space shuttle launch attempt. An approximate total flowrate of 15,000 scfm GN_2 (5,000 scfm @ 5,850 psi and 10,000 scfm @ 150 psi) begins about 14 hours prior to launch. The GN_2 flows are intended to purge all air from the space shuttle, which takes about four hours, before loading the cryogenic propellant. In the event of a scrubbed space shuttle launch, GN_2 flows would continue, at flowrate of 15,000 scfm, for an additional four hours to inert the vehicle after drainback of cryogenic propellant.

Likewise, GHe flows begin approximately 14 hours prior to a space shuttle launch at a total flowrate of 1,000 scfm. Also, GHe flows would continue fours after a space shuttle launch is declared at the same flowrate.

The detailed launch flowrate profile is not constant as alluded to above, however, for the purposes of this study, a constant flowrate is sufficient level of detail.

In summary, a scrubbed launch attempt consumes more purge gasses than a successful launch.

Other Launch Pads and Vehicles

The launch vehicles from Cape Canaveral Air Force Station (CCAFS) have similar operations as the space shuttle from a qualitative perspective, however, the quantities of purge gases consumed and the duration launch flows vary. For the purposes of this study, all launch pad and processing buildings will be connected by a GN_2 and GHe pipeline, with the GHe originating from the CCF. All launch pads share the common distribution pipeline system.

For Gaseous Helium, the Delta IV vehicle consumes ~ 20 scfm daily. The Atlas vehicle does not require daily purges and consumes GHe only during the launch countdown. For that, GHe flows 2 hrs prior to launch at a total flowrate of 1000 scfm. For the Delta vehicle, flows vary from 50 scfm to 16500 scfm for ~ 1.2 million scfm from L-12 through launch.

For Gaseous Nitrogen, the Atlas vehicle's daily consumption rate is ~250 scfm. The approximate Atlas GN2 flowrate of 10000 scfm begins about 2hrs prior to launch. No GN2 data is available for the Delta vehicle.